SECTION 3 - INVESTIGATING PLUMES

The development of a simple and universally applicable model of turbidity induced by capital and maintenance dredging associated with largely cohesive sediments is considered practically impossible at present (Pennekamp *et al*, 1996). When considering the specific sphere of aggregate extraction, which occurs within a limited range of environmental boundaries (water depth, geology, distance to market *etc.)*, the prognosis is more optimistic. Nonetheless, the variability of the marine environment and dredging operations may restrict the development of generic guidelines to those of defining 'Best Practice' for study and monitoring thereof, with recourse to site specific investigations for individual Environmental Assessment and Licence application.

With increasing requirements for assessing the impact of the plume on the seabed, fish stocks and benthos *etc*., greater quantification of the levels of suspended solids within the plume has been required. In Section 2 we identified the sources for plume formation associated with commercial aggregate dredging in particular. The scale of the operations requires proper targeting of monitoring effort, competently planned to maximise resources and minimise excessive costs.

The primary source terms required for assessment of the plume impact have been outlined earlier. This Section outlines some of the methods that are available for measurement of both the source terms (for predictive capabilities) and monitoring methods (for refinement of the predictive models) available. Competent, well executed field measurements provide indisputable evidence of the impacts measured on the survey day and are invaluable. Rigorous field calibration of equipment, *in situ*, is indispensable.

3.1 Variability Of Natural Systems

Prior to attempting to measure suspended solids concentrations (SSC), or changes in SSC attributable to dredging, knowledge must be obtained of the background SSC likely to be encountered and the range of natural variability that may be expected during the monitoring period. Table 3.1 lists values obtained for total particulate matter (as seston).

Interpretation of the results of fieldwork and, especially, modelling, must be viewed in the context of the range of natural variation in suspended solids concentrations. Results from a limited number of measurements in the English Channel (HR Wallingford, 1993) suggest a storm range of 8ppm to 6ppm and calm condition results of 0.01ppm to 12ppm (surface to near bed respectively). Subsequent modelling indicated an increase above background levels of up to 5ppm for two tides and 1ppm for as many as 6 tidal cycles. These results appear significant, until compared with more extensive field sampling campaigns obtained over greater periods in similar areas of the English Channel (Table 3.1).

Reference	Locality	Comments	dry wt (mg/l)
Bassindale (1943)	Bristol Channel (UK)	At Weston-Super-Mare	30-900
Postma (1961b)	Wadden Sea	coastal	1000
Manheim *et al* (1972)	Gulf of Mexico, USA	surface (offshore)	0.125
Chave (1965a)	SW Florida, Caribbean	surface	5
Chester & Stoner (1972)	English Channel	surface	1.719
Chester & Stoner (1972)	Irish Sea	surface	1.680
Buss & Rudolfo (1972)	Cape Hatteras, USA	surface (offshore)	0.1
Buss & Rudolfo (1972)	Cape Hatteras, USA	midwater (offshore)	1-2
Buss & Rudolfo (1972)	Cape Hatteras, USA	bottom (offshore)	0.5-2
Gajewski & Uscinowicz (1993)	Baltic Sea	depth average	1.8
HR Wallingford (1997)	Owers Bank, UK	depth average	0-30
HR Wallingford (1997)	Rye Bay & Harwich	depth average, storms	220-410
Dyer & Moffat (1992)	southern North Sea	depth average - summer	5-30*
Dyer & Moffat (1992)	southern North Sea	depth average - winter	38-42*
Environment Agency (1992-4)	English Channel	surface	<2 - 76*
Environment Agency (1992-4)	English Channel	midwater	<3 - 97*
Environment Agency (1992-4)	English Channel	bottom	<2 - 76*

Table 3.1 *Selected values of seston (dry weight). Values marked * are given as Suspended Solids concentration (modified from Moore, 1977; Dyer & Moffat, 1992; HR Wallingford, 1993; Environment Agency, 1997)*

Recent long term results prepared by Stevenson (1992, *in* HR Wallingford, 1996) considers that SSC need to be established over a three month period (at a minimum) to determine the relationship between tidal range and SSC. Little quantified data exist on the requirements for relating SSC to seasonal variations, but data spanning at least 2 years would be required.

3.2 Measurements Of Turbidity

Measurement of turbidity is often perceived as a generally lower cost option than extensive sampling and testing of suspensates. Turbidity can be measured in a number of ways, the simplest of which is a white circular 'Secchi Disc', some 300mm in diameter, lowered into the water column until no longer visible from the surface. From this depth the Coefficient of Extinction is determined. Electronic turbidity measuring methods are grouped into optical transmissivity, optical backscatter and acoustic backscatter techniques.

With the development of optical transmissivity and optical backscatterance techniques, turbidity has been expressed in terms of Jackson Turbidity Units (JTU) or Nephelometry Turbidity Units (NTU), which are approximately equivalent. More recently the Formazin Turbidity Units (FTU) are quoted which are referenced to a Standard Solution suitable for field deployments. Pyle & Griffin (1974, *In:* Moore, 1977) suggest legal turbidity standards should ultimately be defined in terms of light requirements or silt tolerance of organisms needing protection and it may therefore be realistic to define permissible levels as percentages above background. However, detailed knowledge on the interaction of suspended solids and tolerance levels is site specific both in the mineralogy of the disturbed sediments and in the type of biological community disturbed.

3.2.1 Optical Transmissometer

The most common method, for which there are numerous products on the market with slight technical and performance differences, is that of the optical transmissometer. This records the extinction in light between the emitter and receiver that is dependent on the frequency of the light source, optical path length, water composition, size and refractive index of the particles and sediment concentration. A monochromatic light source of approximately 660nm wavelength is least affected by dissolved constituents of seawater. This is passed over a fixed optical pathlength, commonly 50 - 250 mm, for recording by a photodiode receptor.

Some instruments use a beam splitting arrangement to avoid potential problems in degradation of the light source. The relationship between beam attenuation and concentration is linear for a given particle composition and is generally determined empirically using filtered sample calibration at the site of interest. A range of Standard Formazin turbidity solutions may also be prepared for calibration with site samples. The maximum particle size measurable is approximately 50µm. The system is not suitable for sand suspension measurements, *i.e.* particles greater than 63µm diameter. Concentrations up to 5g/l are measurable using progressively shorter transmission pathlengths. Measurements will be affected by small air bubbles in the water column and possibly by other factors such as humic acid from peaty soil (HR Wallingford, 1996). For use in scenarios where sunlight may cause problems, transmissometers are also available which utilise an infra-red light source.

3.2.2 Optical Backscatter

This method utilises an 850-950nm infrared source and a silicon photodetector. Infrared radiation is scattered by the particles in front of the photodetector. The level of the photocurrent is linearly proportional to the mass concentration of the scattering particles. Optical backscatterance techniques have been developed which are suitable for muds (up to 5000mg/l), silts and sands (up to 100,000mg/l).

The sensitivity will vary according to the particle size, shape and refractive index and may vary by more than a factor of 200 for different sediments. This enforces the requirements for accurate calibration on site, and for re-calibration should the particle sizes or composition differ significantly. Any fines will grossly distort a calibration based on predominantly sandy sized sediments

3.2.3 Acoustic Backscatter

Acoustic Doppler current profiling techniques utilise the transmission of a beam of sound into the water column by 3 or 4 highly directional 2.5 degree beamwidth) transducers arranged in a 'Janus' configuration, inclined at 30 degrees to the vertical. The transducers are driven by a common power amplifier, but with four independent receiver channels. Data is acquired from the ADCP Deck Box using a PC running the mission planning, acquisition and post-processing software 'Transect' supplied by RD Instruments. Backscattered sound from plankton, small particles, air bubbles and small scale inhomogenities in the water ('scatterers') are received by the transducer.

The received signal differs by a Doppler frequency shift proportional to the relative velocity difference between transducer and scatterers. A rapid and continuous series of time based 'range-gated' transmissions enables a profile of the water column, divided into 'bins' which may be as small as 0.25m, to be computed knowing the precise geometry of the beams and a measured or assumed value for the speed of sound in water. Each cell or ‘bin’ of data is allocated velocity components in x, y and z directions. Bins are grouped into ‘ensembles’, which are recorded instantaneously (during the plume tracking exercise) or can be averaged over time or distance (as for current metering or wide scale oceanographic investigations). These data can then be manipulated either in real-time or post-processed to provide detailed representation of the water velocity movements through the water column.

The fundamental assumption is made in that the ‘scatterers’ will be moving at the same rate as the cell of water they are in. The transducer may be stationary, or velocity and heading can be input from external sources *e.g.* from a Global Positioning System (GPS) sensor and gyro compass.

Alternatively velocity can be determined using *bottom tracking* of the seabed by the 4th beam.

Collecting such density of data by impellor or electro-magnetic current meter (EMCM) methods would be prohibitively costly. The primary function of Doppler current profiling techniques is to record continuous current velocities through depth and, depending on the equipment, dynamically using a moving boat. A secondary function of some systems enables the operator to display the acoustic strength of the returned signals for each bin. This will be affected by the SPM. When used in Vessel Mounted (VM) (Figure 3.2.3a) mode this provides a graphic illustration of relative differences in acoustic backscatter, and hence represents relative variations in suspended solids concentration (Figure 3.2.3b).

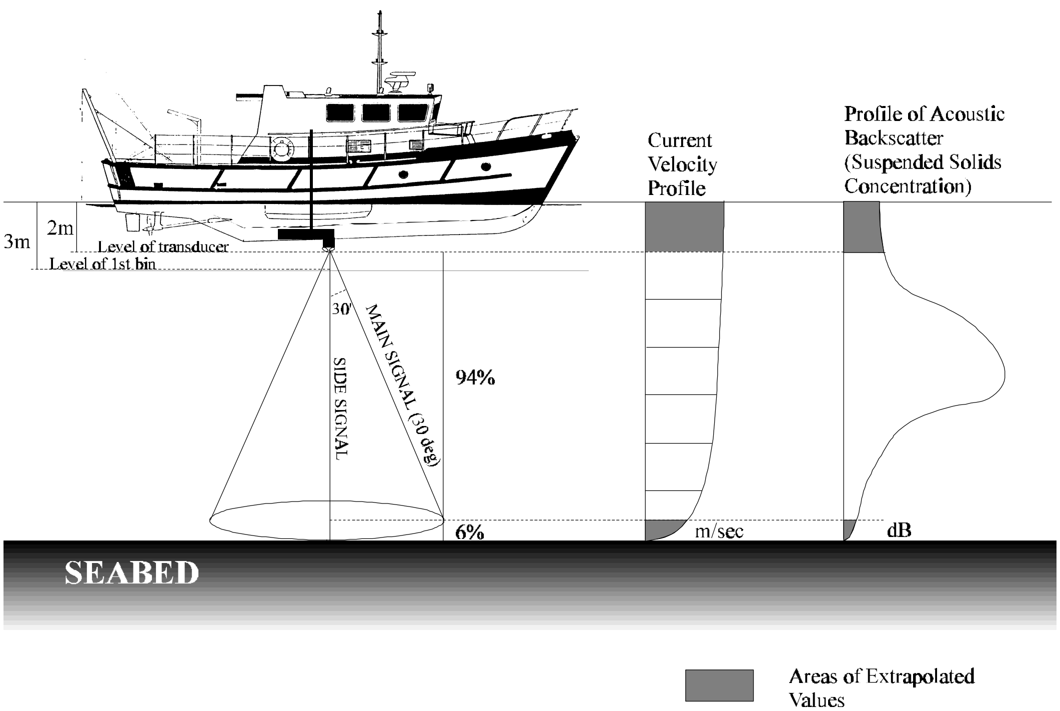

Figure 3.2.3a *Deployment arrangement for Vessel Mounted Acoustic Doppler Current Profiler (VMADCP) as developed during this study for Continuous Backscatter Profiling. Upper and lower part of current and suspended sediment profiles are calculated by extrapolation based on values within measurable range*

Since the early 1980s, Acoustic Doppler Current Profiler have become routine instruments for physical oceanographers and they are now fitted to many oceanographic research vessels. Doppler current profiling and acoustic backscatter measurements have been used since the late 1980s for observing distributions of suspended particulate matter, particularly zooplankton following the work of Flagg & Smith (1989). Recently, its’ use has been extended for observing sediments suspended by dredging and dredged material disposal operations, particularly cohesive sediments in the U.S.A., (*see, for example,* Thevenot & Kraus, 1993; Ogushwitz, 1994) and studying wastewater outfalls (Dammann *et al*, 1991). The usefulness of ADCP techniques as interdisciplinary instruments are now well established.

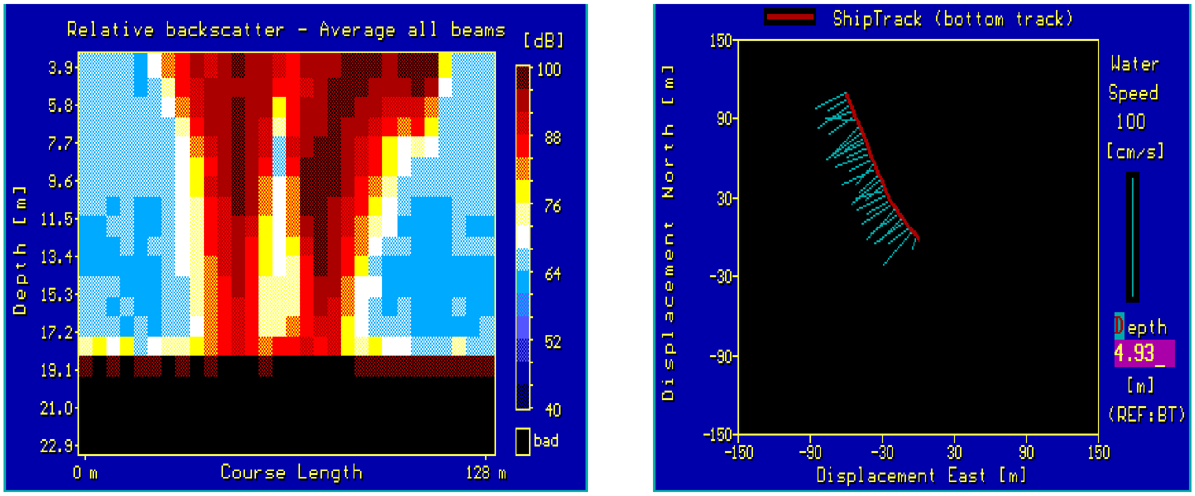

Figure 3.2.3b *Acoustic Doppler Current Profiler™ screen dump showing plume of suspended sediment either side of dredge vessel, immediately astern. Higher suspended solids concentrations are shown in darker colours, the seabed appears black. Clear waters appear in light blue. The darker returns on the starboard side of the ship (right hand side of the figure) reflect the combined overspill and reject plume, whereas the port side of the ship contains only material overspilled. The independent plumes formed either side of the vessel are separated at this distance astern, and are just joining together at depth. Right side shows current velocities proportional to 'stick' length, and direction, recorded simultaneously, whilst traversing along the transect at left.*

There are some significant limitations when using Doppler current profiling techniques for plume monitoring. The most critical is the presence of air bubbles in the water column. Air bubbles transmit the sound signal at a significantly different speed to that of the surrounding waters (due to compression) and will induce considerable noise into the displayed results. It is not possible to circumvent them. When monitoring the passage of a vessel, the wake will appear similar to that of a plume, requiring detailed field notes to explain the apparent 'plume'. Further fieldwork with gravimetric analysis of suspended matter from the monitoring location enables site specific correlation tables to be generated and thus provide conversion to SSC.

The transect shown in Figure 3.2.3b must be viewed bearing in mind the presence of air bubbles and their acoustic signature, caused not only by the motion of the vessel, and the action of the propellers, but also by the 'plunging effect' of the overboard discharge. As will be shown later, it is considered that the sediments within the plume may have air bubbles attached to the particles (which act as buoyancy) and will mask the true acoustic signature of the suspended sediments.

It is presently generally considered for bio-oceanographic monitoring that acoustic backscatter from ADCP cannot be practically calibrated at sea by users (*see* Roe & Griffiths, 1996). Calibration difficulties have meant that virtually all measurements presented have been based on relative backscatter measurements. These relative data are useful for providing semi-quantitative distribution patterns, but they are not comparable over different hydrographic regimes because of the variation in sound absorption with temperature and salinity. Furthermore they cannot be used to compare backscatter at different depths, and they will inevitably provide generalised backscatter/biomass relationships (Roe *et al*, 1996).

Working on oceanographic-scale plankton investigations, recent work by Roe *et al* (1996) improves these relative data by comparing the mean volume backscattering strength (MVBS) within each depth cell of the ADCP using the manufacturers calibration data together with the *in situ* temperature and salinity conditions and the internal electronics temperature and noise levels. This is then compared to concurrent temperature and salinity data from a towed undulating hydrographic sensor platform (SeaSoar) in order to accurately calculate the sound absorption coefficient α, a principle component in determining absolute values for measured backscatter.

The following section outlines techniques for determining suspended solids concentrations and also outlines recent investigations into the use of ADCP equipment for measuring the suspended solids concentrations of plumes generated by various types of dredging activities.

3.3 Measurements Of Suspended Solids Concentrations

3.3.1 Water Sampling

Water sampling devices are as diverse in appearance as they are in complexity. There are numerous Patent and Trademark models available on the market although many are variations on a theme. The simplest form of sampling will be a bucket on a line for use in the surface waters. For deeper waters, sampling bottles with spring loaded plugs or valves at each end are attached to a weighted line and lowered to the required depth. Operation cycle can be of the open-close or close-open-close type.

The bottle can be triggered by sliding a messenger weight down the suspension wire and thus tripping a release mechanism, for example ELE Water Trap, N.I.O, Niskin, van Doorn and Ruttner sampling bottles. The CB sampling device uses a small DC current to trap a sample. The Casella bottle is operated by a sharp pull on the lowering line.

The maximum size of samples generally available from water sampling bottles is about 10 litres although equipment of at least 30 litres capacity is available. A string of bottles may be arranged in a *cast* or bottles may be arranged in a ‘rosette’ formation.

In situations where suspended solids concentration is known to be low, larger samples are required and these will generally be obtained by pump sampling. In depths greater than approximately 35m the pumps will have to be submersible. Pump sampling however has time delays due to the time taken for a discrete sample from a certain location to pass from the suction point to the delivery and storage point.

If the pump capacity is too low, or the settling velocity of larger particles of sediment too high, such larger particles may tend to be left behind in the rising suction tube, therefore artificially reducing the mean particle size. The limitations of pump sampling and possible underestimation of particle sizes have been well documented (*see, for example,* Nelson & Benedict, 1951; Crickmore & Aked, 1975).

3.3.2 Gravimetric Analysis

Laboratory analysis of discrete samples by filtration remains a standard reference method for determining suspended sediment concentrations. Known volumes of seawater are passed through pre-weighed, washed membrane filters of known pore size *e.g.* Millipore 0.45µm +/- 0.02µm, under suction (1/3 ATM) and rinsed with distilled water. The filters are dried at 75^{o}C to constant weight.

The difference in weight of the membrane will be that attributable to the total suspended particulate matter. There are many newer laboratory methods available for determination of suspended solids concentrations involving, for example, centrifuges, radioactive absorption, laser diffraction *etc*. but all have inherent difficulties.

3.3.3 Particle Size Distribution

For examining the dispersion of a plume it is essential to know the range of material sizes that will be dispersed. Particle size analysis is a standard laboratory procedure and a variety of methods are available, depending on the size range of the sample to be tested. Laser diffraction techniques apply to the smaller fractions, less than 5µm. However this analysis is usually carried out on fully disaggregated sediments, which may obscure information pertaining to the *in situ* behaviour of the sediments.

3.3.4 Acoustic Backscatter

The ADCP Deck Box maintains a feedback voltage to the transducers at a constant signal voltage level. The feedback control voltage (Automatic Gain Control - AGC) required varies according to the intensity of the received echo at the transducer, *i.e.* is proportional to the level of acoustic backscatter. The AGC values are the average of the four individual beam values. The AGC value is converted to relative backscatter (dB) depending on several environmental factors including the electronics temperature, factory calibration of the transmitter and receiver and the beam pattern and sensitivity of the transducers. At a typical electronics temperature of 28^{o}C, the relative backscatter conversion equates to 0.42dB/AGC count.

Absolute backscatter has been calculated (*see, for example,* Roe *et al*, 1996) for each depth layer (removing the effects of spherical spreading of the beam, attenuation and changes in the isonified volume) according to the RD Instruments’ Technical Note (1990) and following the concept of determining the mean volume backscattering strength (MVBS). Detailed consideration of such procedures is considered outwith the scope of this thesis.

A number of investigators have further attempted to correlate the backscatter sound strength (dB) of a returned signal with suspended solids concentration (mg/l) with varying degrees of success (Thevenot & Kraus, 1993; Tubman *et al*, 1994; Ogushwitz, 1994). Land *et al* (1994) report statistically acceptable correlation with optical silt meters and water samples for sediment in the range 5 - 75µm with a mean particle diameter 10µm and concentrations up to 1000mg/l.

Lohrmann & Huhta (*In:* Tubman *et al*, 1994) calibrated a 2.4MHz BroadBand ADCP in a purpose-built laboratory calibration tank using material obtained by grab from the seabed of the site to be studied. Although suspended solids concentrations determined by the ADCP were considered to agree 'reasonable well' with the water sample analyses, the maximum error was considered to be ± 60% at 50mg/l. This is largely explained by the theory of Rayleigh backscattering used by the ADCP, which itself can only be accurate to ± 50%. Thevenot & Kraus (1993) hypothesised that flocculation of the material could be a contributing factor to the differences between laboratory and field calibrations.

The techniques involve very careful and rigorous calibration by field sampling which must be repeated at frequent intervals, especially when particle characteristics such as mineralogy and refractive index are expected to change. Table 3.3.4 summarises the measurements that must be recorded during the survey in order to correlate backscatter strength with suspended solids concentrations.

Within this project, the use of Doppler current profiling techniques, in particular in Vessel Mounted configurations, has concentrated on accurately representing the gross morphology of the plume in real-time. This enhances the positioning of other sampling equipment such as water bottles or pump sampling apparatus within the plume for acquiring the suspended solids concentrations.

During post-processing the concentration of solids within a water sample can be confidently placed into perspective within the plume and so apply that concentration to immediate regions of equal acoustic strength to facilitate building graphic representations of the plume behaviour. Correlation of the acoustic strength of the return with suspended solids concentrations has not been attempted.

Speed of sound throughout water column	Corrects for	Beam spreading
Salinity gradient throughout water column	Corrects for	Water absorption
Temperature gradient throughout water column	Corrects for	Water absorption
Particle size expected throughout survey	Corrects for	Beam attenuation
Particle density and compressibility	Corrects for	Beam attenuation
Supply voltage to equipment	Corrects for	Power output variations
Temperature of the electronic circuits	Corrects for	Amplification circuitry

Table 3.3.4 *Table of minimum measurements that must be collected during Doppler current profiling surveys in order to correlate acoustic backscatter with suspended solids concentration (modified from Land* et al, *1994)*

The US Army Corps of Engineers (USACE) Dredging Research Program (DRP) undertaken between 1988 and 1995 at a cost of $35 million has investigated many facets of applied research and development to dredging operations. A significant study by this project was the development of the PLUme MEasurement System (PLUMES) (Kraus & Thevenot, 1992) which also utilised commercially available broad band acoustic Doppler current profiling equipment. The results have been successfully used to document the actual movement of the sediment plume for resource agencies, who were concerned that the plume did not impinge on nearby environmentally sensitive biological regions (Hales, 1995). At least $5 million were saved in not having to conduct extensive environmental studies related to designation of new disposal sites at these locations.

The results obtained both through this research and also reported recently world-wide demonstrate the enormous potential for ADCP operations providing real-time data acquisition and representation of hydrographic and oceanographic conditions. Conventional sampling programmes are enhanced through efficient targeting of resources and confidence in the resultant data. However, analysis of backscatter data for correlation with suspended solids concentrations must take account of the fact that ADCP observations may represent concurrent changes in particle concentration and particle morphology without discmination.

3.3.5 Aerial Photography

Observation of plumes developed by dredging activities is often easily observed by aerial photography. In good conditions this will clearly show the surface expression of a 'plume' (Plate 3.3.5). It has been known for commercial air traffic to report the presence of a major 'oil pollution incident' to the Coastguard, which on investigation has proved to be the surface plume from intensive dredging activities. The results from this study, however, clearly indicate that such comparison of a dredge plume with an 'oil-spill' is sensational and inappropriate.

Plate 3.3.5 *TSHD Sand Harrier*

Modern aerial photogrammetric techniques are such that, given suitable marker buoys located about a plume by differential GPS techniques, accurate measurements of the surface expression of the plume may be made.

3.3.6 Satellite Imagery

Whiteside *et al* (1995) report the use of satellite imagery to illustrate the contrasting natural turbidity regime which exists around Hong Kong. Images may be produced with sufficient resolution to identify the plumes from individual vessels. However, processing of data is presently perceived as costly, and is likely only to be of benefit to major dredging operations, such as in Hong Kong. Technological developments may however, within only a few years, allow such information to become realistically appropriate.

3.3.7 Seabed landers

A number of recent offshore investigations in the U.K. have developed the use of small seabed 'landers'. These frames are deployed on the seabed and host an array of instrumentation to monitor both background and enhanced water quality parameters. Equipment used includes optical and acoustic backscatter sensors for turbidity, electromagnetic current meters, pressure sensors and time-series water sampling devices for suspended solids measurements.

3.4 Monitoring Strategies

The development of plumes are a comparatively short-lived affair compared with many other oceanographic observations. The monitoring strategy must therefore be designed mindful of the fact that results will fluctuate both over very short distances (metres) and in time (seconds).

If historical background data on natural suspended solids concentrations and turbidity are not available at a sufficient resolution for the study area, it will be necessary to obtain such information. Background levels may be established over a period of several months for tidal component variations, or at least one year for seasonal variations. These requirements dictate remote monitoring equipment, and the development of the benthic landers provides a suitable long term frame upon which to mount such campaigns. Concurrent information on wave conditions, tidal velocities, wind velocities *etc*. will also be required.

It is necessary to consider the sampling frequency of long term deployed equipment. Solid state data loggers have increasingly large storage capacities and deployment periods, largely due to improvement in battery technology. A popular approach is to 'burst sample' for perhaps thirty seconds every fifteen minutes and record the average figures. This will account for the majority of oceanographic variations of short (wave motions) and medium (tidal components) term variations. There may be considerable differences for specific requirements, and these are treated comprehensively in the standard oceanographic texts (*see, for example*, Tolmazin, 1985)

HR Wallingford (1974) report variations in instantaneous output from silt transmissometers of up to 20% from the mean for a series of twenty, three second measurement bursts. Stevenson (1992) reports significantly greater variation for higher concentrations (up to 1000ppm) which exemplifies the smoothing effect that sampling by pumps may have on averaging instantaneous variations.

For the purposes of plume monitoring it is essential to know (a) where the plume is and (b) where the sampling equipment is in relation to the plume.

3.4.1 Continuous Backscatter Profiling (*CBP*)

Acoustic Doppler current profiling equipment provides the most suitable technique available today for real-time monitoring of the formation of a plume. Used in a complementary role to siltmeter and water sampling activities, modification of the sampling strategies can be made during the progression of the survey based on in the field observations.

'*Continuous backscatter profiling*' (CBP) may be considered analogous to continuous seismic profiling

(CSP). Detailed descriptions of the principles of using the acoustic backscatter function of the ADCP™ can be found in Land *et al* (1994) and Weiergang *et al* (1995).

Continuous observations of the strength of acoustic signals returned by particles in the water column are processed in real-time to create on screen displays with horizontal time and vertical water depth axes. The colouring of the individual bins of data are user configurable and relative to the strength of the returned echoes and hence the amount of ‘scatterers’ in the water column. This may include organic and inorganic particles, air bubbles *etc*.

The monitoring strategy may be designed in a number of ways using a suitable coastal survey vessel. Firstly a survey programme may observe successive transects across and along the plume axes recording the variation in acoustic signal strength with the ADCP™. The transects are arranged consecutively further downstream of the dredging operation, with one transect upstream before and after the campaign to establish background conditions.

If a midwater drogue with surface marker is deployed immediately downstream of the dredge operation, each transect across the plume may pass adjacent to the drogue. That is to say each transect will observe the same parcel of water at different times after release of material to the water column. The apparent time based settling rate of the material may then be observed.

Alternatively, the vessel may hold station adjacent to the drogue surface marker and continuous observation of the apparent settling characteristics of the plume observed.

The acoustic backscatter function of the ADCP™ can be used with considerable success to efficiently display a real-time graphical representation of the gross morphology of the plume. However, even with careful planning and control it is both difficult and essential to ensure that the water samples obtained can be correlated to a specific ‘bin’ of data recorded by the ADCP™.

Within this project the ADCP™ has been used principally to position the sampling equipment within the plume and have confidence that the sample analysis results are applicable to maxima, minima or otherwise. Other workers, (*see for example* Land *et al* 1994; Weiergang *et al*, 1995), have taken this concept further and attempted to correlate the acoustic strength with suspended solids concentration, a matter receiving considerable debate at present.

To produce competent analysis of the ADCP™ data, the position of the ADCP™ survey vessel and the dredge vessel are required to some degree of accuracy, best provided by Global Positioning System (GPS) techniques operating in Differential mode (dGPS). Ensuring that the two vessels are operating on the same datum, position accuracies better than 5m should be readily attainable.